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(54) LOW THERMAL EXPANSION AND HIGH RIGIDITY CERAMIC SINTERED BODY

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[Abstract]

[Problems]

15 It is an object of the present invention to provide a ceramic  
sintered body with low thermal expansion, which is superior in  
thermal and mechanical stabilities compatibly having a high  
specific rigidity and a low coefficient of thermal expansion.  
[Means to Solve the Problems]

20 In an aspect of the present invention, a ceramic sintered  
body with low thermal expansion and high rigidity of the present  
invention has a crystal structure of hexagonal closest packing  
structure, and comprises solid solution crystal grains  
substantially represented by the formula:  $Mg_aLi_bFe_cAl_dSi_eO_f$   
(wherein, a ranges from 1.8 to 1.9, b ranges from 0.1 to 0.3, c  
25 ranges from 0 to 0.2, d ranges from 3.9 to 4.1, e ranges from 6.0  
to 7.0, and f ranges from 19 to 23). Further, lattice constants  
of the solid solution crystal grains are within the following  
ranges:  $a_0 = 9.774$  to  $9.804$  Angstrom, and  $c_0 = 9.286$  to  $9.330$  Angstrom,  
and relative density of the sintered body is not less than 98%.

30

## [Scope of Claims for a Patent]

[Claim 1] A ceramic sintered body with low thermal expansion and high rigidity, characterized in that said ceramic sintered body has a crystal structure of hexagonal closest packing structure, and comprises solid solution crystal grains substantially represented by the formula:  $Mg_aLi_bFe_cAl_dSi_eO_f$  (wherein, a ranges from 1.8 to 1.9, b ranges from 0.1 to 0.3, c ranges from 0 to 0.2, d ranges from 3.9 to 4.1, e ranges from 6.0 to 7.0, and f ranges from 19 to 23).

10 [Claim 2] A ceramic sintered body with low thermal expansion and high rigidity according to claim 1, wherein lattice constants of said solid solution crystal grains are in the following ranges:  $a_0 = 9.774$  to  $9.804$  Angstrom, and  $c_0 = 9.286$  to  $9.330$  Angstrom.

[Claim 3] A ceramic sintered body with low thermal expansion and high rigidity according to claim 1 or 2, wherein said sintered body has a relative density of not less than 98%.

## [Detailed Description of the Invention]

[0001]

[Technical Field to Which the Invention Belongs]

20 The present invention relates to a ceramic sintered body with low thermal expansion and high rigidity, which is superior in thermal stability and specific rigidity, to be used for members for precision control devices and optical instruments which do not accept variation in dimension and shape by thermal expansion and shrinkage due to change in temperature, or members which are required to have a high thermal shock resistance.

[0002]

## [Description of Related Art]

Conventionally, as a material to be used on condition that thermal stability is required, low thermal expansion metal materials such as Invar alloy (Fe-Ni based) and Super-Invar alloy (Fe-Ni-Co based); low thermal expansion glass such as quartz glass ( $SiO_2$ ) and titanium-oxide-containing quartz glass ( $SiO_2-TiO_2$ ); and low thermal expansion ceramic such as aluminium titanate ( $TiO_2 \cdot Al_2O_3$ ), eucryptite ( $Li_2O \cdot Al_2O_3 \cdot 2SiO_2$ ),  $\beta$ -spodumene ( $Li_2O \cdot Al_2O_3 \cdot$

4SiO<sub>2</sub>), petalite (Li<sub>2</sub>O · Al<sub>2</sub>O<sub>3</sub> · 8SiO<sub>2</sub>) and cordierite (2MgO · 2Al<sub>2</sub>O<sub>3</sub> · 5SiO<sub>2</sub>) are known. These materials are superior in thermal stability with such small thermal expansion coefficient as not more than  $1.2 \times 10^{-6}/^{\circ}\text{C}$  at the vicinity of room temperature, but have a specific rigidity, which is represented by a ratio of Young's modulus to specific gravity, as low as less than 45 GPa/g/cm<sup>3</sup>. Consequently, these materials have problems such as easy deformation by external force or dead weight in use as a member, for which dimensional stability and thermal shock resistance are required, together with low resonance frequency with large amplitude in vibration of a member.

[0003]

For example, invar alloy has comparatively lower thermal expansion coefficient as around  $1.2 \times 10^{-6}/^{\circ}\text{C}$  at the vicinity of room temperature and a comparatively higher Young's modulus as 144 GPa among the low thermal expansion materials, but specific rigidity is as low as 18 GPa/g/cm<sup>3</sup> because of high specific gravity thereof. Further, Super-Invar alloy is inferior in mechanical stability, because it has a specific rigidity as low as 17 GPa/g/cm<sup>3</sup>, despite of low thermal expansion coefficient as  $0.13 \times 10^{-6}/^{\circ}\text{C}$ .

[0004]

Quartz glass has thermal expansion coefficient of as low as  $0.48 \times 10^{-6}/^{\circ}\text{C}$ , but specific rigidity is insufficient as 33 GPa/g/cm<sup>3</sup>, and titanium-oxide-containing quartz glass has extremely low thermal expansion coefficient as  $0.05 \times 10^{-6}/^{\circ}\text{C}$ , but specific rigidity is as low as 33 GPa/g/cm<sup>3</sup>, resulting in inferior mechanical stability.

[0005]

Further, aluminium titanate exhibits negative expansion with thermal expansion coefficient of  $-0.8 \times 10^{-6}/^{\circ}\text{C}$ , but has extremely small specific rigidity as around 2 GPa/g/cm<sup>3</sup>. Lithium-alumino-silicate based low thermal expansion ceramic such as eucryptite,  $\beta$ -spodumene and petalite have small thermal expansion coefficients as  $-5$  to  $1 \times 10^{-6}/^{\circ}\text{C}$ , but their specific rigidities are as low as around 35 GPa/g/cm<sup>3</sup>, resulting in inferior

mechanical stability. Fine sintered body of cordierite has more superior specific rigidity as around 50 GPa/g/cm<sup>3</sup> compared with the above various low thermal expansion materials, but thermal expansion coefficient is around  $0.5 \times 10^{-6}/^{\circ}\text{C}$ , which cannot be  
5 regarded as sufficiently low.

[0006]

In order to lower thermal expansion coefficient of cordierite, which gives comparatively higher specific rigidity, an invention described in JP-A-61-72679 discloses a method in which auxiliary  
10 crystalline phases such as a  $\beta$ -spodumene phase and a spinel phase coexist together with a cordierite phase as crystalline phases, reporting that lowering of thermal expansion can be more effectively realized as compared with a single phase of cordierite. Also, for the similar purpose, an invention described in  
15 JP-A-10-53460 discloses a dense ceramic, in which a petalite phase, a spodumene phase and a cordierite phase are coexisting as crystalline phases, reporting that the thus obtained ceramic is superior in thermal shock resistance. Further, an invention described in JP-A-58-125662 discloses a method for producing a  
20 ceramic, in which zircon is coexisting in cordierite, by adding zirconium compound and phosphor compound into cordierite, reporting that the thus obtained sintered body is superior in thermal shock resistance. However, thermal expansion coefficients of these materials cannot be said to be sufficiently  
25 low, and thermal and mechanical stabilities thereof cannot be sufficient as a member for precision control devices and optical instruments or a member, for which a high thermal shock resistance is required.

[0007]

30 [Problems to be Solved by the Invention]

As described above, in the conventional low thermal expansion ceramic materials, a material having small thermal expansion coefficient has low specific rigidity, and a material having high specific rigidity has thermal expansion coefficient of not  
35 sufficiently low. Consequently, such thermal stability that an

absolute value of thermal expansion coefficient is, for example, not more than  $0.1 \times 10^{-6}/^{\circ}\text{C}$  while high specific rigidity is maintained at such a high level as  $45 \text{ GPa/g/cm}^3$ , has not been secured, and the problem that the conventional low thermal expansion ceramic materials lack thermal reliability as a member for precision structure has been still remaining unsolved. It is an object of the present invention to provide a ceramic sintered body with low thermal expansion and high rigidity, which is superior in thermal and mechanical stabilities compatibly having high specific rigidity and low thermal expansion coefficient.

[0008]

[Means to Solve the Problems]

In an aspect of the present invention, a ceramic sintered body with low thermal expansion and high rigidity of the present invention has crystal structure of hexagonal closest packing structure, and comprises solid solution crystal grains substantially represented by the formula:  $\text{Mg}_a\text{Li}_b\text{Fe}_c\text{Al}_d\text{Si}_e\text{O}_f$  (wherein, a ranges from 1.8 to 1.9, b ranges from 0.1 to 0.3, c ranges from 0 to 0.2, d ranges from 3.9 to 4.1, e ranges from 6.0 to 7.0, and f ranges from 19 to 23).

[0009]

In the above ceramic sintered body, lattice constants of the solid solution crystal grains are preferably within the following ranges:  $a_0 = 9.774$  to  $9.804$  Angstrom, and  $c_0 = 9.286$  to  $9.330$  Angstrom. More preferably, relative density of the above ceramic sintered body is not less than 98%.

[0010]

[Best Mode for Carrying Out the Invention]

The present inventor, after conducting various studies extensively, has found out that in a sintered body composed only of a single phase of solid solution substantially represented by the formula:  $\text{Mg}_a\text{Li}_b\text{Fe}_c\text{Al}_d\text{Si}_e\text{O}_f$  except unavoidable impurities, and having crystal structure of hexagonal closest packing structure, absolute value of thermal expansion coefficient at the vicinity of room temperature and specific rigidity can be controlled in

each range of not more than  $0.1 \times 10^{-6}/^{\circ}\text{C}$  and not less than 45 GPa/g/cm<sup>3</sup>, respectively, by controlling content of each element within a specified range. When a second phase such as an amorphous phase having large thermal expansion coefficient and a spinel phase having a cubic system of crystal structure are present in the solid solution phase represented by the formula:  $\text{Mg}_a\text{Li}_b\text{Fe}_c\text{Al}_d\text{Si}_e\text{O}_f$ , sufficiently low thermal expansion coefficient cannot be obtained. Further, in order to obtain high specific rigidity, it is desirable that a second phase such as an amorphous phase having low specific rigidity, a  $\beta$ -spodumene phase having a tetragonal system of crystal structure and a  $\beta$ -quartz solid solution phase having a hexagonal system of crystal structure other than the solid solution phase represented by the formula:  $\text{Mg}_a\text{Li}_b\text{Fe}_c\text{Al}_d\text{Si}_e\text{O}_f$  does not exist. The solid solution crystal grains of the present invention are substantially represented by the formula:  $\text{Mg}_a\text{Li}_b\text{Fe}_c\text{Al}_d\text{Si}_e\text{O}_f$ . In the formula, a preferably ranges from 1.8 to 1.9. When a is smaller than 1.8, specific rigidity decreases and a second phase corresponding to spodumene phase tends to be easily formed. Contrary, when a is larger than 1.9, coefficient of thermal expansion becomes larger than  $0.1 \times 10^{-6}/^{\circ}\text{C}$ . In the formula, b preferably ranges from 0.1 to 0.3. When b is smaller than 0.1, thermal expansion coefficient becomes larger than  $0.1 \times 10^{-6}/^{\circ}\text{C}$ , and contrary, b larger than 0.3 lowers specific rigidity. In the formula, c preferably ranges from 0 to 0.2. When c is over 0.2, thermal expansion coefficient becomes large and specific rigidity is lowered. When c is smaller than 0.05, the sintered body assumes white color, and when c is in a range from 0.05 to 0.2, the sintered body assumes gray color. In the formula, d preferably ranges from 3.9 to 4.1. When d is smaller than 3.9, specific rigidity is lowered, and when d is over 4.1, thermal expansion becomes coefficient significantly large because an alumina phase tends to be formed as a second phase. Further, e in the formula preferably ranges from 6.0 to 7.0. When e is smaller than 6.0, thermal expansion coefficient becomes large because  $\mu$ -cordierite crystal phase may be remaining in the sintered body. Contrary, when e is larger

than 7.0, specific rigidity is significantly lowered. Still further,  $f$  in the formula preferably ranges from 19 to 23. When  $f$  is smaller than 19, thermal expansion coefficient becomes large, and when  $f$  is larger than 23, specific rigidity is significantly lowered.

5 [0011]

Moreover, in the ceramic sintered body of the present invention, lattice constants of the solid solution crystal grains, which can be analyzed using the X-ray diffraction method on the ground surface of the sintered body, are preferably within the following ranges:  $a_0 = 9.774$  to  $9.804$  Angstrom, and  $c_0 = 9.286$  to  $9.330$  Angstrom. In any case of when  $a_0$  is smaller than  $9.774$  Angstrom or larger than  $9.804$  Angstrom, as well as when  $c_0$  is smaller than  $9.286$  Angstrom or larger than  $9.330$  Angstrom, such sufficiently small thermal expansion coefficient that an absolute value at the vicinity of room temperature is not more than  $0.1 \times 10^{-6}/^{\circ}\text{C}$  can not be obtained.

[0012]

Further, the ceramic sintered body of the present invention preferably has relative density of not less than 98%. The relative density less than 98% is not preferable due to significantly lowered specific rigidity.

[0013]

The solid solution phase represented by the formula:  $\text{Mg}_a\text{Li}_b\text{Fe}_c\text{Al}_d\text{Si}_e\text{O}_f$  of the present invention can be synthesized by reacting a compact composed of mixed powder of relating compounds which is prepared so that each element is in a specified molar ratio. In another way, a powder consisting of the solid solution of  $\text{Mg}_a\text{Li}_b\text{Fe}_c\text{Al}_d\text{Si}_e\text{O}_f$  may be synthesized in advance by means of mixing, calcinating and pulverizing treatments in powdery state, or electromelting treatment of the mixed powder, prior to molding and sintering. As raw materials to be used, known raw materials containing each element of Mg, Li, Fe, Al, Si and O, such as magnesium oxide ( $\text{MgO}$ ) powder, magnesium hydroxide ( $\text{Mg}(\text{OH})_2$ ) powder, lithium oxide ( $\text{Li}_2\text{O}$ ) powder, lithium carbonate ( $\text{Li}_2\text{CO}_3$ ) powder, iron oxide ( $\text{Fe}_2\text{O}_3$ ,  $\text{Fe}_3\text{O}_4$ ) powder, aluminium oxide ( $\text{Al}_2\text{O}_3$ ) powder, silicon oxide

(SiO<sub>2</sub>) powder, spinel (MgAl<sub>2</sub>O<sub>4</sub>) powder, spodumene (LiAlSi<sub>2</sub>O<sub>6</sub>) powder and petalite (LiAlSi<sub>4</sub>O<sub>10</sub>) powder, can be utilized. Any combination of raw materials may be used, so long as the solid solution satisfying the ranges of a to f in the formula: Mg<sub>a</sub>Li<sub>b</sub>Fe<sub>c</sub>Al<sub>d</sub>Si<sub>e</sub>O<sub>f</sub> of the solid  
5 solution of the present invention can be obtained.

[0014]

The ceramic sintered body with low thermal expansion and high rigidity obtainable according to the present invention has crystal structure of hexagonal closest packing structure, and  
10 comprises solid solution crystal grains substantially represented by the formula: Mg<sub>a</sub>Li<sub>b</sub>Fe<sub>c</sub>Al<sub>d</sub>Si<sub>e</sub>O<sub>f</sub> (wherein, a ranges from 1.8 to 1.9, b ranges from 0.1 to 0.3, c ranges from 0 to 0.2, d ranges from 3.9 to 4.1, e ranges from 6.0 to 7.0, and f ranges from 19 to 23), with lattice constants being preferably within the  
15 following ranges: a<sub>0</sub> = 9.774 to 9.804 Angstrom, and c<sub>0</sub> = 9.286 to 9.330 Angstrom, and further, with relative density of the above ceramic sintered body being preferably not less than 98%. As a result of a combination of these conditions, the ceramic sintered body exhibits such extremely low thermal expansion coefficient  
20 as not more than 0.1 x 10<sup>-6</sup>/°C in an absolute value at the vicinity of room temperature at which the material is most frequently used as a member, and also such high specific rigidity, represented by a ratio of Young's modulus to specific gravity, as 45 GPa/g/cm<sup>3</sup>. Thus, the problem to obtain a sintered body superior in thermal  
25 and mechanical stabilities having low thermal expansion coefficient while specific rigidity is maintained at a high level, has been solved.

[0015]

[Examples]

30 Examples of the present invention will be described together with Comparative Examples hereinbelow.

[0016]

Powders of raw materials selected from magnesium oxide (MgO) powder (mean grain size: 0.2 μm), magnesium hydroxide (Mg(OH)<sub>2</sub>)  
35 powder (mean grain size: 0.5 μm), lithium oxide (Li<sub>2</sub>O) powder (mean



grain size: 1  $\mu\text{m}$ ), lithium carbonate ( $\text{Li}_2\text{CO}_3$ ) powder (mean grain size: 2  $\mu\text{m}$ ), iron oxide ( $\text{Fe}_2\text{O}_3$ ) powder (mean grain size: 3  $\mu\text{m}$ ), iron oxide ( $\text{Fe}_3\text{O}_4$ ) powder (mean grain size: 3  $\mu\text{m}$ ), aluminium oxide ( $\text{Al}_2\text{O}_3$ ) powder (mean grain size: 0.6  $\mu\text{m}$ ), silicon oxide ( $\text{SiO}_2$ ) powder (mean grain size: 0.5  $\mu\text{m}$ ), spodumene ( $\text{LiAlSi}_2\text{O}_6$ ) powder (mean grain size: 5  $\mu\text{m}$ ) and petalite ( $\text{LiAlSi}_4\text{O}_{10}$ ) powder (mean grain size: 4  $\mu\text{m}$ ) were mixed in the blending ratios described in Table 1, in a ball mill for 4 hours using water as a solvent, to obtain mixed powders. Thus obtained mixed powders were then dried, molded and sintered. Molding conditions were cold isotactic press by hydraulic pressure at 140 MPa, to mold plate-like specimens of 60 x 60 x 15 mm. Sintering was conducted by the pressure-less sintering (sintering temperature: 1250 to 1420°C, time keeping: 2 to 12 hours) in oxidation atmosphere.

[0017]

Quantitative analyses on molar ratios of the solid solution phase of  $\text{Mg}_a\text{Li}_b\text{Fe}_c\text{Al}_d\text{Si}_e\text{O}_f$  in the resulted sintered bodies were performed using an inductive coupling plasma emission spectral analyzer (ICP method). Crystal structures of primary crystalline phase and auxiliary crystalline phase in the sintered body were analyzed by the X-ray diffraction method on the ground surfaces of the sintered bodies, and lattice constants of primary crystalline phase,  $a_0$  and  $c_0$ , were determined from lattice planar spacing of (110) plane and (002) plane, respectively, obtained in the above analyses. Specific gravity and relative density of the sintered body were measured and calculated by the Archimedes method. Thermal expansion coefficient at the vicinity of room temperature was measured as mean thermal expansion coefficient at 20 to 25°C in accordance with JIS-R3251, using a double optical pass type laser thermal expansion meter of the Michelson laser interference system. Young's modulus was measured in accordance with JIS-R1602, by the ultrasonic pulse method at room temperature. Specific rigidity was obtained by dividing the value of Young's modulus by specific gravity.

[0018]

Results of the tests are shown in Table 1.

[0019]

As apparent from Table 1, the ceramic sintered body with low thermal expansion of the present invention comprises hexagonal system of solid solution crystal grains represented by the formula:  $Mg_aLi_bFe_cAl_dSi_eO_f$  (wherein, a ranges from 1.8 to 1.9, b ranges from 0.1 to 0.3, c ranges from 0 to 0.2, d ranges from 3.9 to 4.1, e ranges from 6.0 to 7.0, and f ranges from 19 to 23), lattice constants of the solid solution crystal grains are within the following ranges:  $a_0 = 9.774$  to  $9.804$  Angstrom, and  $c_0 = 9.286$  to  $9.330$  Angstrom, and further, relative densities of the sintered bodies are not less than 98%. In comparison with the results in Comparative Examples, the sintered body of the present invention exhibits extremely low thermal expansion coefficient as not more than  $0.1 \times 10^{-6}/^{\circ}C$  in absolute value of thermal expansion coefficient at the vicinity of room temperature, and also high specific rigidity, which is represented by a ratio of Young's modulus to specific gravity, as  $45 \text{ GPa/g/cm}^3$ . Thus, it is demonstrated that the sintered body has low thermal expansion while maintains a high level of specific rigidity. On the other hand, as shown in Comparative Examples, it is found that thermal expansion coefficient becomes large and specific rigidity becomes inferior, when a tetragonal system of  $\beta$ -spodumene phase, a hexagonal system of cordierite phase, a cubic system of spinel phase, and the like are present as a second phase (auxiliary phase).

[0020]

[Table 1]

Table 1 (1)

	No	MgO wt%	Mg(OH) <sub>2</sub> wt%	Li <sub>2</sub> O wt%	Li <sub>2</sub> CO <sub>3</sub> wt%	Fe <sub>2</sub> O <sub>3</sub> wt%	Fe <sub>3</sub> O <sub>4</sub> wt%	Al <sub>2</sub> O <sub>3</sub> wt%	SiO <sub>2</sub> wt%	LiAlSi <sub>4</sub> O <sub>6</sub> wt%	LiAlSi <sub>4</sub> O <sub>10</sub> wt%
Examples	1	11.2	-	0.5	-	-	0.8	30.1	57.4	-	-
	2	11.4	-	-	-	-	-	28.8	54.8	5.0	-
	3	-	15.0	0.3	-	1.1	-	28.4	55.2	-	-
	4	10.2	-	-	1.5	2.1	-	28.0	58.2	-	-
	5	-	15.6	-	-	-	0.8	27.3	51.3	5.0	-
	6	-	15.9	0.3	-	1.2	-	29.4	53.2	-	-
	7	10.6	-	-	-	1.7	-	27.2	49.8	-	10.7
	8	11.4	-	-	-	-	0.6	30.4	54.4	3.2	-
	9	-	15.1	-	1.2	0.5	-	28.0	55.2	-	-
Comparative Examples	10	13.8	-	-	-	-	-	34.9	51.3	-	-
	11	-	16.7	0.1	-	-	-	30.0	53.2	-	-
	12	11.9	-	-	-	1.0	-	30.0	44.1	13.0	-
	13	10.1	-	-	-	-	0.6	29.2	45.6	-	14.5
	14	-	18.2	0.1	-	1.2	-	32.3	48.2	-	-
	15	9.7	-	-	-	-	5.6	30.7	49.6	4.4	-
	16	12.3	-	0.8	-	-	-	38.9	48.0	-	-
	17	6.2	-	-	-	1.2	-	28.5	61.8	-	2.3
	18	-	17.0	-	-	0.4	-	30.3	50.1	2.2	-

wt%: % by weight

[0021]

[Table 2]

Table 1 (2)

		Crystal structure of sintered body		Lattice constants of primary crystal		a to f values of solid solution phase $\text{Mg}_8\text{Li}_6\text{Fe}_6\text{Al}_4\text{Si}_6\text{O}_7$ *					
		Primary crystal	Auxiliary crystal	$a_0$ (Å)	$c_0$ (Å)	a value	b value	c value	d value	e value	f value
Examples	1	Hexagonal <sup>1)</sup>	Nil	9.778	9.310	1.88	0.23	0.08	4.00	6.48	21.03
	2	Hexagonal <sup>1)</sup>	Nil	9.778	9.290	1.90	0.18	0.00	3.98	6.50	20.96
	3	Hexagonal <sup>1)</sup>	Nil	9.776	9.320	1.85	0.15	0.10	4.02	6.63	21.32
	4	Hexagonal <sup>1)</sup>	Nil	9.800	9.290	1.80	0.29	0.19	3.91	6.90	21.80
	5	Hexagonal <sup>1)</sup>	Nil	9.802	9.288	1.90	0.11	0.05	4.05	6.15	20.38
	6	Hexagonal <sup>1)</sup>	Nil	9.778	9.290	1.87	0.15	0.10	3.95	6.05	20.07
	7	Hexagonal <sup>1)</sup>	Nil	9.802	9.290	1.88	0.25	0.15	4.08	6.95	22.18
	8	Hexagonal <sup>1)</sup>	Nil	9.776	9.320	1.81	0.11	0.05	3.92	6.01	19.82
	9	Hexagonal <sup>1)</sup>	Nil	9.778	9.312	1.89	0.23	0.05	4.00	6.70	21.46
Comparative Examples	10	Hexagonal <sup>2)</sup>	Nil	9.770	9.352	-	-	-	-	-	-
	11	Hexagonal <sup>1)</sup>	Nil	9.774	9.340	1.95	0.05	0.00	4.01	6.05	20.09
	12	Hexagonal <sup>2)</sup>	Tetragonal <sup>3)</sup>	9.772	9.346	-	-	-	-	-	-
	13	Hexagonal <sup>1)</sup>	Hexagonal <sup>4)</sup>	9.776	9.320	1.75	0.33	0.05	4.00	5.30	18.57
	14	Hexagonal <sup>1)</sup>	Cubic <sup>5)</sup>	9.776	9.340	1.85	0.05	0.10	3.96	5.80	19.52
	15	Hexagonal <sup>1)</sup>	Nil	9.806	9.284	1.55	0.15	0.45	4.01	5.60	19.29
	16	Hexagonal <sup>1)</sup>	Cubic <sup>5)</sup>	9.772	9.346	1.88	0.35	0.00	5.00	5.60	20.76
	17	Hexagonal <sup>1)</sup>	Hexagonal <sup>4)</sup>	9.806	9.284	1.05	0.05	1.00	3.85	7.20	22.25
	18	Hexagonal <sup>1)</sup>	Nil	9.772	9.348	1.93	0.08	0.03	4.02	5.70	19.43

\*: Described only when  $\text{Mg}_8\text{Li}_6\text{Fe}_6\text{Al}_4\text{Si}_6\text{O}_7$  solid solution phase is present in the sintered body.

1):  $\text{Mg}_8\text{Li}_6\text{Fe}_6\text{Al}_4\text{Si}_6\text{O}_7$  Solid solution phase

2):  $\alpha$ -Cordierite phase

3):  $\beta$ -Spodumene phase

4):  $\mu$ -Cordierite phase

5): Spinel phase

[0022]

[Table 3]

Table 1 (3)

	No	Specific gravity g/cm <sup>3</sup>	Relative density %	Coefficient of thermal expansion (20-25°C) X 10 <sup>-6</sup> /°C	Young's Modulus GPa	Specific rigidity GPa/g/cm <sup>3</sup>
Examples	1	2.38	99	0.05	120	50.4
	2	2.41	99	-0.01	130	53.9
	3	2.39	99	0.00	127	53.1
	4	2.37	98	0.08	114	48.1
	5	2.47	99	0.02	139	56.3
	6	2.43	99	-0.02	133	54.7
	7	2.38	99	0.09	113	47.5
	8	2.48	99	0.01	131	52.8
	9	2.40	99	0.07	122	50.8
Comparative Examples	10	2.50	99	0.43	135	54.0
	11	2.41	99	0.13	127	52.7
	12	2.30	98	0.17	99	43.0
	13	2.24	90	0.25	80	35.7
	14	2.28	93	0.31	87	38.2
	15	2.53	95	0.18	109	43.1
	16	2.51	99	0.15	110	43.8
	17	2.56	98	0.22	118	46.1
	18	2.23	89	0.05	83	37.2

[0023]

[Effect of the Invention]

- 5           The present invention enables to provide a ceramic sintered body with low thermal expansion and high rigidity, which has been extremely improved in thermal and mechanical stabilities, with low thermal expansion coefficient while a high level of specific rigidity is maintained. Thus, industrial usefulness of the present
- 10 invention is very large.